Shingles in Paving Project: Paving Demonstration

King County
Department of Transportation
Road Services Division

King County Linkup

King County
Department of
Natural Resources and Parks
Solid Waste Division

Completed roadway, September 2009

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King County LinkUp

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1. EXECUTIVE SUMMARY

Incorporating recycled asphalt shingles (RAS) in hot-mix asphalt (HMA) can achieve two seemingly independent objectives: divert significant quantities of material from disposal and reduce the amount of virgin asphalt needed in road paving projects. **The Shingles in Paving Project is an initiative of LinkUp, a program of the King County Solid Waste Division (KCSWD) in Washington State. The long-term goal of the Project is to establish a strong local HMA end market for RAS that captures the resource value of tear-off shingles and diverts this material from landfills.**

The paving demonstration of the Shingles in Paving Project was a multi-year effort to design and demonstrate the use of RAS in HMA on a local paving project. **The specific goal of the paving demonstration was to demonstrate that the addition of RAS to HMA had no significant impact on pavement performance.**

This report describes the history of the paving demonstration, details the methodology, presents findings and conclusions, and describes next steps to further advance the use of RAS in HMA. Accompanying appendices present key resource documents developed during the paving demonstration.

BACKGROUND

LinkUp focuses on expanding markets for selected recyclable and reusable materials, to support the Solid Waste Division's goal of conserving natural and renewable resources. **Beginning in 2006, LinkUp targeted tear-off asphalt shingles as a priority because a large quantity of tear-off asphalt shingles generated in King County is disposed in landfills, local shingle recycling infrastructure is not firmly established, and shingles are successfully recycled in other parts of the country.**

The LinkUp team (consisting of LinkUp staff and supporting consultants) researched potential end markets for tear-off asphalt shingles. The research suggested four potential end uses for tear-off shingles: an additive that contributes asphalt to HMA; a loose aggregate supplement to be used in road base construction; an additive that contributes asphalt and aggregates to cold patch material; and a combustible material to be burned as a fuel supplement. In 2007, the LinkUp team identified HMA paving applications as the most promising end use for this material. The benefits of using RAS in HMA include increased resistance to rutting, increased diversion from landfills, reduced greenhouse gas emissions, and reduced paving costs resulting from replacing virgin asphalt binder in HMA with recycled asphalt binder generated from RAS.

Initial research revealed significant local interest from the private sector in collecting and using this material as well as several efforts among transportation agencies nationwide to test and document the use of RAS in HMA. Ten other states have specifications or procedures that allow the use of RAS in asphalt pavements. Also on the national level, the American Association of State Highway and Transportation Officials (AASHTO) has developed a provisional specification for the use of RAS in HMA.

Based on local stakeholder feedback, LinkUp initiated the paving demonstration in 2007 to test the use of RAS derived from tear-off asphalt shingles in HMA on a public road.

PAVING DEMONSTRATION IMPLEMENTATION

Implementing the paving demonstration involved two main components. **First, LinkUp assembled a team of experts and stakeholders to address the interests of key market players, ground the study in reality, and provide technical and other resource contributions.** King County Road Services Division (KCRSD) agreed to sponsor the paving demonstration on a King County roadway and the Washington State Department of Transportation (WSDOT) agreed to lead the HMA mix design; the participation of both agencies was fundamental to the success of the paving demonstration. **Second, the assembled team designed and carried out the technical aspects of the paving demonstration to achieve the following objectives:**

- Align the demonstration with the interests and standards of participating agencies and stakeholders.
- Design the study to evaluate the performance of RAS-modified HMA with a high degree of certainty; a key strategy was to isolate RAS as a variable.
- Capture objective engineering data in an effort to gain wide acceptance of the performance test results.

To this end, the LinkUp team with other partners and stakeholders developed stringent criteria, standards, and protocols to implement each critical phase of the paving demonstration including the following:

- **Roadway selection.** Roadway selection criteria were applied to five candidate roadways to select the one most appropriate for the project.
- **Material specifications: RAS and HMA.**
    - The RAS specification was developed using two approaches: (1) work with paving experts on the team to establish performance standards, and (2) gather input from state and local regulatory agencies to ensure compliance with health, safety, and environmental requirements. Asbestos sampling and testing protocols were modified during implementation to address asbestos concerns. Additional testing ensured that the accepted final RAS supply met the performance standards.
    - WSDOT led the design of the HMA specification that addressed three issues unique to this demonstration: the amount of RAS to incorporate, the estimated amount of binder replacement from the RAS, and whether or not to use recycled asphalt pavement (RAP).
- **Procurement and contracting for RAS and paving.** KCRSD evaluated alternative strategies for procuring the RAS product and the paving. Additionally, KCRSD included bidder qualifications in the evaluation criteria to ensure that the selected contractor had prior experience using RAS in HMA. In accordance with procurement laws governing construction contracts, KCRSD awarded the

paving demonstration contract to Woodworth & Company (Woodworth).

- **Paving installation and evaluation.** In September 2009, a two-mile stretch of road in South King County, Washington, was paved in four test sections to evaluate the use of three percent RAS derived from tear-off asphalt shingles and 15 percent RAP within HMA. Tests were conducted prior to, during, and immediately following paving to achieve the study objectives.

FINDINGS AND RESULTS

A series of tests were conducted on the RAS and HMA products to verify compliance with project specifications and performance standards. In addition, a series of pavement tests were conducted to evaluate pavement performance. The following findings highlight the key outcomes of initial pavement performance tests.

- Testing verified that all but one Test Section substantially met project specifications and materials standards.
- In one RAS Test Section, high asphalt binder and fines content led to low air voids in the HMA job mix. In-place density tests further verified air void loss.
- The finished roadway surface is in near perfect visual condition, comparable to a newly paved traditional HMA roadway.
- Skid resistance testing shows no noticeable change in resistance.

CONCLUSIONS

The paving demonstration fully met two of the three study objectives, and partially met the third objective. To fully meet the third objective, long-term monitoring will be required to gain wide acceptance of the performance test results. **Results from the extensive initial materials engineering tests conducted by the team indicate that using RAS as a part of the HMA mix has had no negative effect on pavement performance.**

In addition, experience with RAS during the paving demonstration resulted in additional findings for future exploration in research and paving demonstrations.

- The RAS appeared to contribute a greater amount of asphalt binder than expected to the total asphalt in the final HMA product.
- Different analytic test methods provided conflicting results for determining if asbestos-containing material (ACM) was present: test results for RAS using polarized light microscopy (PLM) differed from results from transmission electron microscopy (TEM) testing methods, indicating a need to continue to improve upon standard sampling and testing methods for testing for ACM in RAS.
- More stringent visual inspections of tear-off asphalt shingles from an existing stockpile reduced the likelihood of ACM or extraneous materials being included in the final RAS product.

Just as significant, the paving demonstration illustrated the critical importance of a multi-party, partnership approach to such research and development efforts. Without the productive input and engagement of KCRSD, WSDOT, and Woodworth, the paving demonstration may not have been successfully implemented.

NEXT STEPS

In 2010 and beyond, the LinkUp team will continue to advance the development of infrastructure and end markets for RAS from tear-off roofing projects. Building on the successful paving demonstration, the team will engage stakeholders to share findings and results as well as conduct research to explore questions that arose during the paving demonstration. In addition, LinkUp will continue its partnership with KCRSD to monitor and test pavement performance of the test roadway.

2. INTRODUCTION

King County, Washington, is a nationally recognized leader in developing waste reduction, recycling, and recovery programs. LinkUp, a program of the King County Solid Waste Division (KCSWD), focuses on expanding markets for selected recyclable and reusable materials by facilitating an interactive community of businesses, public agencies, and other relevant stakeholders. In 2006, LinkUp identified tear-off asphalt shingles as a priority material for recycling. With limited local recycling infrastructure and end markets for this material, significant quantities of tear-off asphalt shingles are generated in King County and disposed in landfills. Market research identified hot-mix asphalt (HMA) paving applications as the most promising end use for recycled asphalt shingles (RAS).

In 2006, LinkUp initiated the Shingles in Paving Project to work with the local recycling and paving community to establish a strong local HMA end market for RAS that captures the resource value of tear-off shingles and diverts this material from landfills. An important first step in achieving this goal is to work with transportation agencies to conduct a paving demonstration on a public road that incorporates RAS into HMA.

In 2009, LinkUp's multi-year coordinated effort resulted in a local paving demonstration that documents and tests the use of RAS in HMA. The goal of the paving demonstration was to show that the addition of RAS to HMA has no significant impact on pavement performance. Fundamental to achieving this objective has been working with local and state transportation agencies to develop contract specifications and technical requirements for using RAS in HMA.

Key phases of the Shingles in Paving Project are outlined in Figure 1.

Various terms are used to describe asphalt shingles throughout the recycling process. For the purposes of this report, the following definitions are used:

Tear-off asphalt shingles: asphalt shingles generated during re-roofing construction projects

Mixed roofing loads: loads of roofing waste that include a mixture of tear-off shingles and other roofing debris, such as roofing felt, tar paper, and mastic

Whole shingles: tear-off shingles that may have been sorted and screened but have not been ground for recycling

Recycled asphalt shingles (RAS): shingles that have been screened and ground for use in HMA. In this report, RAS refers to material that is derived from tear-off asphalt shingles.

A detailed list of acronyms, abbreviations, and key terms is included in Appendix A.

Whole shingles not yet sorted for use in paving demonstration

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Figure 1. Key phases of Shingles in Paving Project

2006-2007

Phase 1: Background Research

- Identify tear-off shingles as a priority material
- Explore potential end markets
- Research national and local efforts
- Engage stakeholders

2007-2009

Phase 2: Paving Demonstration

- Establish project team
- Secure project sponsor
- Select roadway
- Develop study design
- Establish specifications and standards
- Procure RAS and HMA
- Install paving
- Conduct preliminary testing

2010 and beyond

Phase 3: Next Steps

- Share results
- Engage stakeholders
- Conduct additional research
- Conduct ongoing testing
- Implement additional demonstration projects

Phase 1–The Shingles in Paving Project began in 2006 when King County identified tear-off asphalt shingles as a priority material for reuse and recycling. In 2007, the LinkUp team (consisting of Linkup staff and supporting consultants) identified HMA paving applications as the most promising end use for this material. That same year, the LinkUp team met with key regional stakeholders and transportation agencies to explore local interest in using RAS in HMA. Based on stakeholder feedback, LinkUp initiated the paving demonstration to test the use of RAS in HMA on a public road.

Phase 2–LinkUp staff secured the support of local transportation agencies, state and local regulators, and other key stakeholders (through an advisory group) to guide the design and development of the paving demonstration. In 2008, King County Road Services Division (KCRSD) agreed to sponsor the paving of a test section of King County roadway with RAS incorporated into HMA. KCRSD selected the paving demonstration roadway with assistance from the LinkUp team and the project advisory group, developed specifications, and established testing and sampling protocols.

In 2009, KCRSD and the LinkUp team developed and refined the procurement and contracting process and selected Woodworth & Company (Woodworth) to provide RAS processing and paving services for the paving demonstration. In September 2009, a two-mile stretch of road in South King County, Washington, was paved to test the use of 3 percent RAS and 15 percent recycled asphalt pavement (RAP) within HMA. Preliminary tests on the roadway test section were conducted and documented.

Phase 3–In 2010 and beyond, the Shingles in Paving Project will build on the paving demonstration to advance the development of infrastructure and end markets for tear-off asphalt shingles. The Linkup team will engage stakeholders to share results, conduct research to explore questions that arose during the paving demonstration, and work with local transportation partners to evaluate pavement performance and move toward a permissive HMA specification.

This report documents the Shingles in Paving Project. The balance of the report is divided into five main sections, as described below, and includes a complete set of Appendices.

- **Section 3: Background.** This section briefly describes how HMA was identified as the target end market for tear-off shingles, highlights local and national experience using RAS in HMA, and describes how stakeholders were consulted as part of the initial decision-making process.
- **Section 4: Paving Demonstration Implementation.** This section details the members of the team and the methodology for implementing the paving demonstration, including roadway selection, material specifications, procurement, and paving installation and evaluation.
- **Section 5: Findings and Results.** This section presents the results of testing conducted to verify whether the RAS and HMA products met specifications and to evaluate pavement performance.
- **Section 6: Conclusions.** This section summarizes the outcomes of preliminary testing in terms of pavement performance and provides additional conclusions from the experience.
- **Section 7: Next Steps.** This section describes ongoing and future plans for sharing results and testing and monitoring the roadway test sections.
- **Appendices** follow the main body of the report and include definitions of key terms and acronyms, research memos, a list of resources, stakeholder and advisory group documents, the sampling and testing matrix, the paving demonstration Invitation to Bid, revised sampling and sorting protocols, a report documenting findings from the shingle processor Request for Information, and the KCRSD technical report.

3. BACKGROUND

In 2006, LinkUp identified tear-off asphalt shingles as a priority material for recycling market development. Specifically, tear-off asphalt shingles were selected as a priority for three primary reasons:

1. A large quantity of tear-off asphalt shingles generated in King County is disposed in landfills: in 2004 an estimated 17,000 tons of tear-off asphalt shingles were generated by construction and demolition activities in King County (outside Seattle), while less than 1,000 tons of these materials were recycled. [1]
2. Local recycling infrastructure is not firmly established for this material.

1 King County Waste Monitoring Program Market Assessment of Construction and Demolition Waste Materials, Final Report 2004. Prepared by Cascadia Consulting Group for the King County Solid Waste Division. Page 30.

3. Tear-off asphalt shingles are successfully recycled in other parts of the country.

King County LinkUp conducted a thorough investigation to determine whether and how to move forward with local market development for tear-off asphalt shingles. This section describes the background research and reasoning for electing to initiate a paving demonstration that showcases the use of RAS in HMA pavement.

3.1 Identifying End Markets

In 2006, the LinkUp team researched potential end markets for tear-off asphalt shingles. The research identified four potential end uses for tear-off asphalt shingles:

1. An additive that contributes asphalt to HMA
2. As a loose aggregate supplement to be used in road base construction
3. An additive that contributes asphalt and aggregates to cold patch material
4. A combustible material to be burned as a fuel supplement

LinkUp found the market for shingles as an additive in HMA to be the most established and documented use. A handful of states across the country have been researching and testing the use of RAS (derived from both tear-off and manufactured scrap) for many years. Some of the initial benefits identified by research and testing of RAS in HMA include the following:

- The use of stiffer asphalt binder in the manufacture of asphalt shingles results in increased resistance of the pavement to rutting and increased resistance to low temperature cracking.[2]
- Fewer tear-off shingles are disposed in landfills through recycling of this post consumer material resource.
- Greenhouse gas emissions are avoided due to reduced production of new virgin asphalt binder for use in HMA.
- The cost of paving projects is reduced by replacing costly virgin asphalt with RAS. Over the past few years, the price of asphalt has fluctuated considerably, leading HMA producers "to seek ways of reducing or extending the virgin asphalt cement they use in their products."[3]
- Paving projects using reclaimed materials fulfill green building mandates and increase green collar jobs.

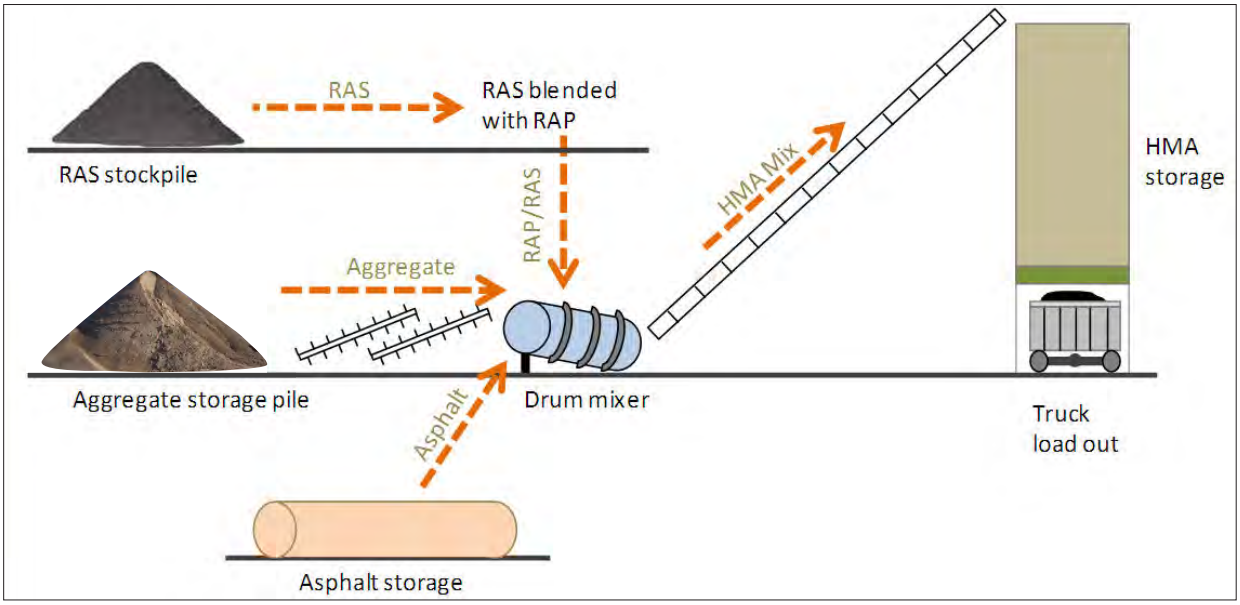
While open to participating and receiving many of the benefits identified above, local transportation

2 Ron Sines (Oldcastle Materials) "Use of Recycled Shingles in HMA Pavements" presentation at the Construction Materials Recycling Association's (CMRA) 4th Asphalt Shingle Recycling Forum, held in Chicago on November 5, 2009.

3 Guidelines for the Use of Reclaimed Asphalt Shingles in Asphalt Pavements, National Asphalt Pavement Association. November 2009. Page 5.

Figure 2. Addition of RAS in HMA Production

RAS is blended with RAP before being incorporated into HMA, as shown in the below diagram.



officials in Washington did not have the prerequisite first-hand experience with RAS in HMA or the necessary local engineering and performance data to consider allowing the use of RAS in HMA on public roads.

Various terms are used to describe shingle recycling and paving industry roles. For purposes of this report, the following definitions are used:

HMA producers: Companies that manufacture HMA from aggregates and asphaltic materials.

Paving Contractors: The road construction companies that install the pavement.

Processors/Recyclers: Companies that convert raw recyclable materials (for example, whole shingles) into a product (such as RAS) that can be used by an end market (such as HMA producers).

A detailed list of acronyms, abbreviations, and key terms is included in Appendix A.

3.2 Exploring Local and National Experience

Beginning in late 2006, the LinkUp team assessed local and national markets for recycled tear-off asphalt shingles. The team conducted local research, interviewed key stakeholders, and explored national efforts to use RAS in HMA. The information below highlights key findings from this research that supported the decision to initiate the paving demonstration as well as more recent markets development activities associated with using RAS in HMA.

Local and Regional Experience Recycling Asphalt Shingles

Though residential roofing and re-roofing activities generate large quantities of asphalt shingle waste, few opportunities exist locally for recycling this material. Until it closed in 2001, the Tacoma Steam Plant accepted asphalt shingles, for a tip fee, to be burned as fuel. There are currently no

plans to reopen the Steam Plant. Since the plant's closing, recyclers in the region have had difficulty finding viable markets for tear-off asphalt shingles. Initial research in early 2006 found that most shingles collected for recycling were burned for fuel, with a limited amount used to make asphalt and aggregate products.

The LinkUp team found significant interest from local HMA producers, paving contractors, and recyclers in participating in tear-off asphalt shingle recycling for use in pavements. In late 2006, the LinkUp team interviewed 19 HMA producers and paving contractors from the Washington Asphalt Paving Association (WAPA) regarding their interest in using RAS in HMA. Four of the companies were interested. These companies were located in King, Snohomish, and Pierce counties. Of the five recyclers interviewed, two were grinding tear-off asphalt shingles for use in road base and the others were interested in collecting and possibly grinding tear-off asphalt shingles. (See Appendix B Research Memos.)

Tear-off asphalt shingle recycling continues to advance locally in terms of the number of companies engaged in recycling. LinkUp is aware of three local processors that grind tear-off shingles for use in HMA. Additionally, one construction and demolition (C&D) processor collects shingles to send to a paving company in eastern Washington for inclusion in HMA. At least three local paving companies are using RAS in HMA on private construction projects and several research projects are underway along the West Coast: Metro Vancouver (B.C.) plans to pave a test site in 2010 using HMA that incorporates RAS; Oregon State University is researching the effects on mix properties of incorporating RAS and RAP into HMA for the Oregon Department of Transportation; and California included sampling tear-off shingles for asbestos as part of a recent statewide waste study.[4,5,6]

At the end of 2009, the National Asphalt Pavement Association (NAPA) reported that eight states had specifications or procedures that allow the use of RAS derived from both tear-off asphalt shingles and manufacturer's scrap in asphalt pavements:[1]

- **Alabama,**
- **Georgia,**
- **Missouri,**
- **Pennsylvania,**
- **South Carolina,**
- **Texas,**
- **Virginia, and**
- **Wisconsin.**

Since the NAPA report, two more states, **Iowa** and **Minnesota**, began allowing the use of RAS from tear-off and manufacturer's scrap asphalt shingles in HMA.

1 *Guidelines for the Use of Reclaimed Asphalt Shingles in Asphalt Pavements* published by NAPA (November 2009). For ordering information, go to the link: http://store.hotmix.org/index.php?productID=702

National Experience Using RAS in HMA

Other state and local departments of transportation have specifications or procedures that allow the use of RAS in asphalt pavements. DOT engineers in several states have conducted field studies of roadways and trails paved

4 Metro Vancouver's newsletter "From Roof to Road" is available online at http://www.metrovancouver.org/Include/invites/AsphaltShingle-Newsletter.htm

5 The report *Preliminary Investigation of RAP and RAS in HMAC* is available at http://www.oregon.gov/ODOT/TD/TP_RES/ResearchReports.shtml.

6 2008 California Statewide Waste Characterization Study. Prepared by Cascadia Consulting Group for the California Integrated Waste Management Board. November 2009. CIWMB Publication Number: IWMB-2009-023. Page 65. http://www.calrecycle.ca.gov/Publications/default.asp?pubid=1346

with HMA containing tear-off RAS. The results of the field studies have shown increased stiffness of the asphalt, decreased cracking, no effect on moisture sensitivity, decreased susceptibility to rutting, and decreased optimum content of virgin asphalt binder. Paving demonstration research memos summarizing the RAS recycling experience nationwide are included in Appendix B.

Asbestos-containing material (ACM) is defined as any material containing more than one percent (1%) asbestos. In Washington State, agencies governing the handling of ACM include L&I and the local air authority, which is fulfilled by Ecology in some regions. In King County, the local air authority is the Puget Sound Clean Air Agency.

State and local DOTs look to the American Association of State Highway and Transportation Officials (AASHTO) for guidance on paving specifications. For this reason, it is significant that in mid-2009, AASHTO published a revised set of specifications for the use of RAS in HMA. Both the original and amended AASHTO specifications provided for the use of both tear-off and manufacturers' shingle scrap.[7]

Also on the national level, research into other end markets for RAS is being conducted. These include using RAS as an alternative fuel source in cement kilns and as a recycled liquid asphalt product.[8,9] There is a growing emphasis on increasing the quality of the tear-off shingle supply. One publicly-funded tear-off shingle recycling project in Colorado is working with roofing contractors to source-separate tear-off shingles during roof replacement, as well as to sample and inspect for asbestos-containing materials (ACM).[10]

For more information on asphalt shingle recycling, please see Appendix C: Resources.

3.3 Involving Stakeholders

In August 2007, the LinkUp team initiated strategic conversations with local and regional transportation agencies including KCRSD, the Seattle Department of Transportation (SDOT), and the Washington State Department of Transportation (WSDOT). The goals of these meetings were to introduce them to the Shingles in Paving Project, to assess knowledge of and interest in using RAS in HMA, and to share technical expertise and research related to other states' experience testing and using RAS in HMA.

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7 AASHTO MP015-09-UL: Standard Specification for Use of Reclaimed Asphalt Shingles as an Additive in Hot Mix Asphalt (HMA). (For ordering information, link to: https://bookstore.transportation.org/item_details.aspx?ID=1420.)

AASHTO PP053-09-UL: Standard Practice for Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in New Hot Mix Asphalt (HMA). (For ordering information, link to: https://bookstore.transportation.org/item_details.aspx?ID=1421.)

8 Use of RAS as an alternate fuel source in cement kilns: "Alternate Market Application for Recycled Asphalt Shingles: Department of Energy (DOE) Report Summary" A presentation by Carmen LaTorre (Owens Corning) at the 4th Asphalt Shingle Recycling Forum held in Chicago, November 6, 2009.

9 Processing of RAS to produce a recycled liquid asphalt product: "Crown Iron Works Company: Asphalt Shingle Recycling Technology"; A presentation by Jeff Scott and Chas Teeter (Crown Iron Works) at the 4th Asphalt Shingle Recycling Forum held in Chicago, November 6, 2009.

10 Roofs to Roads Colorado http://roofs2roadscolorado.org/index.php

Following initial meetings with these key transportation agencies, the LinkUp team assembled approximately 40 stakeholders representing solid waste, health, and air quality agencies; asphalt shingle recyclers and material processors; paving trade organizations; paving contractors; and transportation agencies. With these stakeholders, the team shared information about the use of RAS, evaluated the idea of conducting a local paving demonstration using RAS, and solicited participation in moving forward with the paving demonstration. Stakeholders voiced significant support for a RAS paving demonstration. Over the course of the paving demonstration, the list of stakeholders grew to 150 members. LinkUp has kept these stakeholders informed about the paving demonstration through periodic email updates and a Web site.

4. PAVING DEMONSTRATION IMPLEMENTATION

There were two critical components to the implementation of the paving demonstration. The first was forming a team with the diverse skill set necessary to provide technical input and guidance throughout the entire paving demonstration. The second was developing a study methodology that ensured relevant data were collected so the results of the study would effectively serve the needs of key stakeholders and support LinkUp's long-term market development goals.

4.1 The Team

At the heart of the paving demonstration was a diverse team of staff, technical experts, and stakeholders who played a vital role in shaping, designing, and implementing a successful demonstration project. As described below, the LinkUp team, advisory group, sponsor, core team, and supporting organizations played important roles in designing the paving demonstration to address stakeholder interests, ground the study in reality, and provide staff time, financial, and in-kind contributions. These groups were central to the successful implementation of the paving demonstration.

Kevin Kelsey holds up a sample of RAS during an advisory group meeting in December 2009

4.1.1 LinkUp Team

Formed in 2006, the LinkUp team is composed of staff from KCSWD and supporting consultants from Cascadia Consulting Group, Colehour + Cohen, and Foth Infrastructure & Environment. The LinkUp team performed material and market research, convened stakeholders, and facilitated and managed the paving demonstration.

4.1.2 Paving Demonstration Advisory Group

In late 2007, the LinkUp team formed a Paving Demonstration Advisory Group to guide the design and development of the paving demonstration. The original group was composed of 15 members (which increased to 20) and included public transportation and solid waste agencies, HMA producers and paving contractors, a roofing contractor, C&D materials processors (recyclers), and a regional air quality agency. The advisory group provided valuable input into paving demonstration design and implementation. It helped ensure that the demonstration explored important locally relevant research questions, adequately addressed performance concerns, and—to the extent possible—reflected the common realities for recyclers and HMA producers. A list of advisory group members and the group's charter can be found in Appendix D.

The first advisory group meeting took place in October 2007. In November 2007, several members of the advisory group attended the 3rd Asphalt Shingle Recycling Forum in Chicago (organized by the Construction Materials Recycling Association, or CMRA) to learn more about the latest developments in tear-off asphalt shingle recycling. Between October 2007 and December 2009, the advisory group met four times. Meetings were held to obtain input at critical milestones such as demonstration design, material specifications, and sampling and testing protocol development. Notes from each meeting are included in Appendix D. In addition to formal meetings, advisory group members were informed about developments through regular email communication and the LinkUp Web site.[11] The Web site offers paving demonstration updates, information on partners, resources on asphalt shingle recycling, and research and materials developed in support of the paving demonstration.

4.1.3 Sponsor

Securing a transportation agency sponsor was a critical milestone in the paving demonstration. From the start, both the LinkUp team and the advisory group identified KCRSD as an attractive potential sponsor given King County's potential to grow the local market for RAS in HMA through the large number of paving projects each year on King County roads. The LinkUp team worked diligently to address initial engineering concerns about safety, performance, and liability. LinkUp's approach of engaging WSDOT and technical experts in developing stringent material specifications and testing standards provided greater assurance to KCRSD engineering professionals about product reliability. In addition, the LinkUp team summarized and shared findings from paving demonstrations from across the nation to illustrate how other transportation agencies have managed risk and successfully paved with HMA that included RAS. KCRSD has been an excellent and committed leader of the paving demonstration, with dozens of staff involved from the start to help shape the design all the way through to paving installation and evaluation. KCRSD is leading the pavement performance evaluation.

11 King County LinkUp Shingles in Paving Demonstration Project Web site: http://your.kingcounty.gov/solidwaste/linkup/shingles/paving-demo.asp

4.1.4 Core Team

The core team consisted of KCSWD (project manager), KCRSD (sponsor), WSDOT (HMA mix design lead), and the supporting consultant team. After the contract was awarded, Woodworth became part of the core team as the contracted RAS processor, HMA producer, and paving contractor. In addition, several other key supporters provided critical financial and in-kind contributions to the paving demonstration. The core team and key supporters are described below.

- **KCSWD and LinkUp.** KCSWD, through the LinkUp program, provided funding, project management, and consultant support to the paving demonstration. By facilitating stakeholder engagement and careful coordination of all elements, LinkUp steered the paving demonstration to a successful outcome.
- **KCRSD.** In addition to serving on the advisory group, KCRSD agreed to sponsor and lead the paving demonstration on a King County road. KCRSD identified candidate roads, managed the road selection process, led the development of the study design, managed the paving demonstration from contracting through installation, provided testing for materials and evaluation during construction, and funded additional laboratory testing for asbestos during implementation. The agency will continue to monitor the pavement over the next three years (2010 to 2012). KCRSD contributed tremendous staff support and commitment throughout the paving demonstration.
- **WSDOT.** WSDOT was involved in all aspects of the paving demonstration and offered technical expertise that was highly valued by team members, especially KCRSD as the sponsor for the paving demonstration. In addition to serving on the advisory group, WSDOT provided significant in-kind laboratory services and equipment to test and evaluate RAS, HMA, and the final pavement. WSDOT led the HMA mix design for the paving demonstration. Additionally, WSDOT staff served on the advisory group and attended two Shingle Recycling Forums in Chicago, Illinois (presenting at one), to represent the paving demonstration.
- **Woodworth & Company.** Since its beginning in 1921 from the merger of a building company, a dredging company, and a road paving company, Woodworth has maintained diverse lines of business and now has paving, asphalt production, and roofing recycling divisions.[12] Woodworth has over a decade of experience using RAS in pavements, holds a solid waste handling permit, and is located in Tacoma, Washington. Woodworth served on the advisory group and, through a competitive bid process, secured the KCRSD contract to provide RAS and HMA paving for the paving demonstration. Woodworth was a valuable partner in making this demonstration project successful.
- **The Consultant Team.** Cascadia Consulting Group led the consulting team and supported all aspects of the paving demonstration under the guidance of LinkUp. Foth Infrastructure & Environment provided technical expertise and important linkages to national shingles recycling efforts and research. Colehour + Cohen managed the consultant team contract and subcontracts and provided communication and media expertise as well as meeting facilitation.

12 Seattle Daily Journal of Commerce. Top Projects of the Century in Washington State, #11 Woodworth & Co. - Founded 1921. http://www.djc.com/special/century/wood.html

4.1.5 Regulatory Advisors

There were a number of regulatory advisors who provided significant time and invaluable expertise on the development of the RAS specification. In the Puget Sound area, the agencies listed below fill a regulatory role in at least one part of the process of recycling tear-off asphalt shingles from the roof to the road:

- Public Health – Seattle & King County,
- Snohomish Health District,
- Tacoma-Pierce County Health Department,
- Washington State Department of Ecology (Ecology),
- Puget Sound Clean Air Agency, and
- Washington State Department of Labor and Industries (L&I).

The review and timely approval of the RAS specification was a critical milestone in moving the paving demonstration forward.

4.1.6 Other Financial Support

In addition to in-kind contributions received from KCRSD and WSDOT, these partners provided financial support to the paving demonstration:

- **Seattle Public Utilities (SPU).** In addition to serving on the advisory group, SPU covered the costs for WSDOT to attend the 3rd Shingles Recycling Forum in Chicago in 2007, and provided $10,000 in 2008 to support the advisory group and HMA mix design development by WSDOT.
- **Washington State Department of Ecology.** Ecology awarded LinkUp a Coordinated Prevention Grant for $75,000 in 2008. Ecology also provided critical input on regulatory elements of this work.

4.2 Paving Demonstration Methodology

The core team led the design and implementation of the paving demonstration, with careful attention to roadway selection, material requirements, testing, and monitoring standards to ensure that the paving demonstration met the following three critical study objectives:

- **The paving demonstration was aligned with the interests and standards of participating agencies and stakeholders.** As such, the demonstration was designed to meet the quality and performance standards required by KCRSD, the market development objectives of LinkUp, the regulatory requirements of relevant agencies, and the on-the-ground reality of recycling and paving industries.
- **The study was explicitly designed to evaluate the performance of RAS-modified HMA with a high degree of certainty.** The desired outcome for the paving demonstration was to show that the addition of RAS to HMA had no significant impact on pavement performance. Given this goal, the

study sought to control all variables that normally affect pavement performance (e.g. subsurface conditions, pavement thicknesses, equipment used, personnel, and climate conditions) in order to isolate the RAS variable.

- **Objective engineering data were captured in an effort to gain wide acceptance of the performance test results** from as broad an audience of local city and county transportation professionals as possible.

To this end, the core team, with the support of the advisory group, developed stringent criteria, standards, and protocols for each critical phase of the paving demonstration including **roadway selection, material specifications, sampling and testing protocols, procurement and contracting, and pavement installation and evaluation.** To guide and effectively manage the implementation of the paving demonstration, the core team developed a comprehensive testing matrix, which summarized key tests, responsible parties, the schedule, and estimated costs. The sampling and testing matrix is presented in Appendix E.

The balance of this section describes in greater detail the methodology used to carry out the key phases of the paving demonstration.

4.2.1 Roadway Selection

Selecting the right roadway for the paving demonstration was an important step in laying a strong foundation for a successful paving demonstration. The LinkUp team worked with KCRSD and the advisory group to develop a list of criteria for the ideal roadway characteristics for the paving demonstration. The final road selection criteria were as follows:

SE 416th St (before paving)

- Candidate for thin-lift asphalt overlay paving
- Existing HMA thickness of at least four inches
- Existing condition/level of deterioration
- Consistent and stable subgrade
- No known development planned along the roadway in 10 years that would disturb the integrity of the paved roadway surface
- No or limited drainage issues
- Known traffic volumes and traffic counts with a roadway that had sufficient amount of truck traffic
- Typical two-lane roadway
- Road length a minimum of two miles
- Limited stop-and-go and turning
- Flat and straight roadway

KCRSD developed a selection process to identify the best available roadway for conducting the paving demonstration. The process was to (1) select a short list of King County road candidates that were scheduled for overlay paving in 2009 and that provided the necessary two miles of length for the paving demonstration; (2) develop a weighted selection criteria to evaluate the road candidates; (3) use existing data and, if needed, test road core samples as part of the evaluation; and (4) select the road that scored the highest using the selection criteria.

Applying the criteria to five candidate roadways led to the selection of SE 416th Street near Enumclaw, Washington, for the paving demonstration.

4.2.2 Material Specification and Protocols

The LinkUp team worked with KCRSD, WSDOT, the advisory group, and regulatory agencies to develop material specifications and sampling and testing protocols for RAS and HMA. Specifications were designed to mitigate risk to KCRSD and ensure that the process and final product met performance, health, safety, and environmental standards. This section describes the specification process, key considerations for developing both specifications, and sampling and testing protocols to ensure the materials met the required specifications.

4.2.2.1 RAS Specification

The LinkUp team, KCRSD, and WSDOT, with input from the advisory group and local regulatory agencies, developed the RAS specification to ensure that the RAS product met the quality and performance standards established for the paving demonstration. The RAS product needed to meet gradation and moisture requirements; be substantially free of extraneous waste materials; and be entirely free of whole, intact nails and ACM. In addition, the processor needed to be in compliance with local environmental, health, and safety standards. Key representatives of the King, Snohomish, and Pierce County health departments; Ecology; the Puget Sound Clean Air Agency; and L&I were engaged to help develop, review, and refine the RAS specification to meet regulatory requirements. Written approval of the final RAS specification, after all regulatory comments were addressed, was provided by representatives of these agencies. The RAS specification is further described below. (See Appendix F Section 9-36 for the RAS specification as released with the King County Contract C00455C09 Invitation to Bid (ITB) in June 2009.)

Material Quality Specifications

The quality of the finished RAS product is critical to the overall performance of its use in HMA and the final pavement. The RAS specification included the following requirements to optimize performance of the HMA and ensure that the RAS product is free of ACM.

- **Materials.** Only tear-off asphalt shingles are to be used. Other asphalt roofing products (built up roofing and rolled or sheet roofing) are not acceptable. Incidental amounts of other roofing materials (wood, plastic, metal) are allowed in incoming loads but may need to be separated out to meet extraneous waste materials requirements.

- **ACM.** Incoming loads must be inspected by an Asbestos Hazard Emergency Response Act (AHERA)-accredited inspector. If suspect ACM is found, the load shall be rejected or tested for ACM. If material is determined to contain ACM, the material shall not be used in the demonstration, and local asbestos handling regulations must be followed.
- **Gradation.** The final RAS product shall be processed so that 100 percent passes through a 1/2-inch sieve and a minimum of 95 percent passes through a 3/8-inch sieve.
- **Extraneous Waste Materials.** The final RAS product shall be substantially free of extraneous waste materials and entirely free of whole, intact nails. Lighter extraneous material such as paper, wood, and plastic shall not exceed 1.5 percent by mass. Total extraneous materials including metals, glass, rubber, steel, aluminum from roofing nails or flashing, soil, brick, tars, paper, wood, and plastic shall not exceed 3.0 percent by mass.
- **Moisture Content.** The final RAS product to be used in the HMA should not contain more than 5.0 percent moisture.

RAS Sampling and Testing Requirements

Establishing sampling and testing requirements was an important strategy for verifying that the finished RAS product met all of the material quality specifications. The RAS specification called for KCRSD to have access to observe shingles recycling operations and to take samples directly from the finished RAS product pile upon request. KCRSD was also provided copies of all laboratory testing. The RAS specification dictated the method, frequency, sample size, and test methods for evaluating material quality standards such as gradation, moisture, extraneous materials, and ACM. Sampling and testing procedures referenced established guidelines, such as AASHTO, as well as national and local asbestos regulations.

The RAS specification called for quality control and verification testing on the finished RAS product, after screening and other finishing processes, and stated that the processor shall collect six random samples of the finished RAS product (minimum of 25 pounds each) for testing.

In addition to testing that may have been conducted on suspect materials during incoming load inspections, the RAS specification required asbestos testing on random one pound samples for every ten tons of RAS produced. The samples were to be sent to an accredited asbestos testing laboratory for analysis by polarized light microscopy (PLM). According to Puget Sound Clean Air Agency's Regulation 3, Article IV, asbestos-containing material should be identified with PLM per EPA regulations Appendix E, Subpart E, 40 CFR Part 763, Section l. The RAS specification stated that if ACM is found in the RAS stockpile, the entire stockpile shall not be used for the project and shall be disposed of in accordance with applicable legal requirements at the processor's expense.

Asbestos Sampling and Testing Modifications

This section describes the asbestos sampling and testing modifications made during implementation of the paving demonstration and the reasons they were put in place (please see Appendix G: Revised RAS Sorting, Sampling, and Testing Operations Plan). The following three additional sampling and

testing requirements were not originally included in the RAS specification:

1. Tear-off shingles were carefully inspected visually and hand-sorted to remove prohibited items, such as felt/tar paper, shingles with patching, and built-up roofing.
2. Sorted whole shingles were tested, in addition to the finished RAS product asbestos testing.
3. Transmission electron microscopy (TEM) was used to test whole shingles. TEM is not commonly used to test asphalt shingles but is thought to be a more sensitive test than the standard. Please see textbox on the right for more information.

At the start of the contract, Woodworth proposed using an existing stockpile of finished RAS for the paving demonstration. Though the RAS specification called for a new stockpile with specific receiving and load inspection procedures, KCRSD agreed to consider this material with the following conditions:

- King County would conduct a facility visit to review the incoming load inspection and sorting protocols used for the stockpiled material.
- King County would conduct additional asbestos tests. The County contracted for testing using PLM, as required in the project specifications, as well as additional "more sensitive" TEM testing for added assurance.

Thus, the following testing was performed on random samples of the proposed ground RAS stockpile:

- Six PLM bulk sample tests for asbestos were conducted by Woodworth—all results were "non-detect" for asbestos.
- Twenty PLM tests for asbestos were conducted by King County—all results were non-detect for asbestos.
- Five TEM bulk sample tests for asbestos were conducted by King County—three out of the five samples were found to contain levels of asbestos ranging from 1.64 percent to 5.94 percent asbestos by weight.
- One TEM test for asbestos was conducted by Woodworth—results were non-detect for asbestos.

PLM and TEM Tests for Asbestos

Polarized light microscopy (PLM) is "used to visually estimate the percent of asbestos in bulk samples, such as soil and insulation materials. It can differentiate between asbestos types, but cannot reliably detect asbestos in low concentrations (below 1%)."[1]

Transmission electron microscopy (TEM)– "TEM is more complex than…PLM, and it uses a more sophisticated analytical instrument. TEM can distinguish between asbestos and non-asbestos fibers and asbestos types. It can be used at higher magnifications, enabling identification of smaller asbestos fibers than can be seen by other techniques."[2]

One strategy is to use both methods, especially if the PLM method results in a non-detect for ACM at the lower levels of asbestos around the one percent threshold. "The TEM is a powerful tool to identify fibers too small to be resolved by light microscopy and should be used in conjunction with this method when necessary."[3]

1, 2 U.S. EPA Region 8, Libby Sampling and Analysis web page information sheet; http://www.epa.gov/libby/sampling.html

3 OSHA, 1992. Improved Asbestos Bulk Sample Analysis Test Method http://www.osha.gov/dts/sltc/methods/inorganic/id191/id191.html

Although this first RAS stockpile technically met local and federal asbestos regulations using the PLM testing method, King County rejected it for the project because (1) incoming material was not examined by an AHERA-accredited inspector as required by the contract (the inspector's certificate of accreditation had lapsed) and (2) non-shingle materials, such as roofing felt/tar paper, were not pre-sorted before grinding as required by the contract. The positive TEM test results also raised concerns. Subsequent conversations with King County's testing lab and technical experts revealed ongoing questions about testing RAS (and other bulk materials) for asbestos at low levels—around the one percent threshold. It is the opinion of King County's contracted testing laboratory that the asbestos levels above one percent detected with TEM resulted from roofing material other than asphalt shingles.

To keep the paving demonstration moving and on schedule, King County and Woodworth worked swiftly with technical experts and the testing laboratory to sort, sample, and test a new supply of RAS that would meet requirements and use Woodworth's existing stockpile of whole shingles. King County enlisted the services of an AHERA-accredited roofing materials expert to lead an intensive day of sorting at Woodworth's facility, where a Woodworth crew and members of the core team hand-sorted and visually inspected more than 70 tons of tear-off asphalt shingles and other roofing materials. Very few suspect materials (14 items in all) were detected and sorted out; these materials added up to a very small portion of the total material. Suspect materials included roofing felt or tar paper, asphalt shingles with patching, and built-up roofing with aluminum coating.[13] The following tests were conducted on the final sorted, whole shingles stockpile:

- 12 TEM tests for asbestos on composite samples of whole shingles (representing 91 different shingles)—all results were non-detect for asbestos
- Seven PLM tests for asbestos on the ground RAS—all results were non-detect for asbestos.

This final stockpile was accepted by KCRSD and used in the paving demonstration.

Solid Waste Regulation Compliance

In Washington State, at this time, RAS is a regulated as a solid waste. The agencies that enforce solid waste regulations are the jurisdictional health departments and Ecology. The primary exposures of concern are to ground and surface water and to air quality. The LinkUp team worked with local health departments and Ecology to ensure that solid waste regulations were clearly outlined in the RAS specification.

13 LinkUp contracted with KCRSD's laboratory to perform asbestos testing on the 14 suspect items that were removed during the visual inspections and hand-sorting activities described in Section 4.2.2.1 under Asbestos Sampling and Testing Modifications. The following tests were conducted on these suspect items:

- 14 PLM tests for asbestos—all results were non-detect for asbestos
- Two TEM tests for asbestos on two (2) of the 14 items – both samples were found to contain asbestos; one 1.97 percent asbestos by weight and the other 2.81 percent asbestos by weight of the suspect material or coating. (Sample preparations did not allow for an evaluation of the reliability of PLM vs. TEM testing methods).

Processor Qualifications

Including the solid waste handling regulations discussed above, the RAS specification required the processor to certify that it meet all relevant safety, health, and environmental regulations. In Washington State, the processor must either be permitted as a solid waste handling facility or notify and receive the approval of the proper agencies of the intent to operate under an exemption option. In addition, the processor must have in place a workplace accident prevention program that addresses workplace hazards in accordance with local and state regulations. The RAS specification required the processor to submit verification forms to certify that it met all requirements and standards.

4.2.2.2 HMA Specification

WSDOT served as the primary lead for developing the HMA mix design. For the paving demonstration, the HMA specification needed to address three key questions: (1) the amount of RAS to incorporate, (2) the estimated amount of virgin binder replacement due to the RAS, and (3) whether to include the use of RAP. Typically, 15 percent RAP is used in HMA on King County paving projects. Washington State Standard Specifications permit up to 20 percent RAP in contractor HMA mix designs. Several stakeholders expressed their interest in including both RAP and RAS together in the study design to reflect the standard HMA mixes in use today by local pavers.

In August 2008, KCSWD issued a Request for Information (RFI), based on a well-developed draft of the RAS specification, to identify potential RAS suppliers in the region, learn more about their operations, and request RAS product samples for informational purposes. Three companies responded to the RFI and provided samples of RAS. WSDOT conducted a series of tests on the RAS as well as preliminary mix design testing with the RAS and RAP to determine if RAS, RAP, and HMA could be blended at varied percentages and still meet volumetric property quality standards. The original WSDOT report on testing results for the samples submitted in response to the RFI is included in Appendix H. The results of the analysis are also presented in 5.1.1 RAS Testing Results.

Preliminary test results indicated that adding both RAS and RAP to a typical HMA mix slightly increased the amount of air voids and presented no adverse effects to the volumetric properties. In developing the King County HMA specification, WSDOT referenced the provisional AASHTO standards for the use of reclaimed asphalt shingles and mix design considerations when using RAS as an additive in addition to preliminary testing results of RAS samples submitted in response to the RFI. The final HMA mix design called for exactly three percent RAS and 15 percent RAP, keeping the total recycled materials at 18 percent. This is below the WSDOT maximum of 20 percent RAP in HMA by weight of the total mix. The stakeholders believed this mix design would provide an optimum amount of virgin

binder replacement and still achieve material quality standards. The intent was to keep the total amount of recycled binder under 30 percent to be consistent with the AASHTO standards, which otherwise recommend adjustments to the grade of asphalt or the addition of an asphalt rejuvenator.

Prior to paving, a proposed HMA mix design using 5.4 percent of asphalt binder by total weight of mix was developed by Woodworth. Woodworth submitted this mix design and materials samples to WSDOT for further testing and development of the final HMA mix design. In general, it was determined that the target value for the total asphalt binder content was 5.6 percent by weight of the total mix, including 4.3 percent virgin asphalt binder, 0.6 percent asphalt binder from RAP, and 0.7 percent asphalt binder from RAS. The final mix design is included in Section 5-06 of the King County Contract C00455C09 ITB, which is included in Appendix F.

4.2.3 Procurement and Contracting

KCRSD initially intended to procure the RAS product under a contract separate from paving and to award the paving contract as part of King County's South Overlay Paving Contract, which includes multiple paving projects.[14] The intent of procuring the RAS product separately was to 1) give KCRSD greater control over the RAS product, 2) ensure a level-bidding environment because one of the asphalt paving companies was currently accepting and processing RAS, and 3) for the county to provide the RAS to the paver as a means to encourage several HMA producers to consider this new technology. Thus, KCRSD planned to provide the RAS material to the paving contractor selected for the South Overlay Paving Contract, with the intent of reducing administrative requirements as well as safeguard the paving demonstration against anticipated funding cuts.

The RAS procurement and contracting process was carefully designed to meet three objectives. First, it needed to comply with KCRSD material procurement policies. For instance, decisions about who owned the material at each point had legal implications. Second, the procurement documents needed to specify the RAS so that the actual material purchased would meet the safety and environmental standards of local regulatory agencies. Third, the procurement documents needed to specify RAS so that it would meet materials engineering quality standards for use in HMA. KCRSD issued a request for quotations (RFQ) in February 2009 to shingles processors in the central Puget Sound area to purchase approximately 70 tons of RAS for the paving demonstration. The RFQ was sent to known RAS processors, but none responded.

As a result of the RFQ outcome, KCRSD and the LinkUp team reconsidered the procurement approach. The team realized that bundling RAS into the paving contract would better reflect market interactions between HMA producers/paving contractors and RAS suppliers. The bundled approach also led to separating the paving demonstration from the larger South Overlay Paving Contract, as KCRSD determined that the paving contractor selected for that Project may not necessarily be the best contractor for the paving demonstration. Therefore, KCRSD designed a separate procurement approach to award the paving demonstration contract through a smaller, stand-alone contract. In

14 Each year, King County awards two overlay paving contracts (North King County and South King County). In 2009, the South Overlay Paving Contract amounted to slightly more than 34,000 tons of HMA.

August 2009 KCRSD issued an ITB for these bundled services (excerpts from the King County Contract C00455C09 ITB are available in Appendix F). KCRSD included bidder qualifications in the evaluation criteria to ensure that the selected contractor had prior experience using RAS in HMA. There were two responses to this ITB: Woodworth and Lakeside Industries. In accordance with procurement laws governing construction contracts, KCRSD awarded the contract to Woodworth.

4.2.4 Paving Installation and Evaluation

After two years of design and development, the paving demonstration culminated in September 2009 with the paving of the test roadway. To evaluate the performance of RAS-modified HMA with a high degree of certainty, KCRSD developed a study design that documented existing conditions, established control and test sections, put in place paving and construction monitoring, and outlined post-construction monitoring and evaluation. These activities are described in greater detail below.

4.2.4.1 Existing Condition of Roadway and Test Section Layout

KCRSD conducted pavement condition surveys prior to paving the designated road section to document the existing condition of the pavement. The measurements assist in determining the rate of deterioration and, subsequently, the needs for rehabilitation or repairs. KCRSD conducted the following procedures as part of the pavement condition survey:

- Paving rating experts walked the entire roadway and documented existing crack patterns and other deficiencies in late spring and early summer 2009.
- KCRSD further documented the pavement surface in July 2009 using the WSDOT Distress Data Collection Van to record the pavement profile, including smoothness and rutting, and to video tape the entire roadway surface.
- KCRSD retrieved 16 asphalt cores from the roadway to determine the existing pavement structure. The average pavement thickness measured about 4.5 inches of existing asphalt.
- KCRSD drilled six subsurface borings to determine subsurface conditions.
- KCRSD utilized the WSDOT falling weight deflectometer to provide additional structural testing of the pavement and underlying subgrade.

Results are presented in Section 5.3.1 Pre-Construction Testing and described in greater detail in Appendix I, the KCRSD report.

Prior to any maintenance work completed to prepare the road for construction, initial observations from a driving survey of the roadway suggested that the pavement surface in the first mile (western half of the test section) was in fair condition, exhibiting longitudinal cracking in the roadway wheel

paths at intermittent locations with underlying soils consisting of silty gravels that were generally well consolidated. Pavement conditions on the remaining mile (eastern half of the test section) were in fair to poor condition, exhibiting more distressed areas as compared to the western half of the roadway. In addition, underlying soil conditions in this section of the road generally consisted of less consolidated, silty sands. To accommodate for the variability in pavement and underlying soil conditions the roadway was divided into four separate test sections, each approximately one-half mile in length (see Table 1). This allowed for one section each of the RAP-only and RAP/RAS HMA mixes to be sited on both the western and eastern portion of the roadway.

Table 1. Paving Demonstration Test Section Layout

	Test Section #1	Test Section #2	Test Section #3	Test Section #4
	1/2 Mile	*1/2 Mile*	*1/2 Mile*	*1/2 Mile*
Lane 1 (eastbound)	HMA Mix with 15% RAP	HMA Mix with 3% RAS and 15% RAP	HMA Mix with 3% RAS and 15% RAP	HMA Mix with 15% RAP
Lane 2 (westbound)	HMA Mix with 15% RAP	HMA Mix with 3% RAS and 15% RAP	HMA Mix with 3% RAS and 15% RAP	HMA Mix with 15% RAP

4.2.4.2 Pavement Installation

Road preparation and paving operations for the paving demonstration took place over five days beginning on September 21, 2009. Each of the four test sections required about 1,000 tons of HMA to provide for a single, two-inch thick overlay. As illustrated in Table 1, two of the four test sections of the two-mile stretch were paved with a two-inch-thick overlay consisting of HMA that included three percent RAS and 15 percent RAP (experimental material section), while the other two test sections were paved with a two-inch-thick overlay consisting of HMA that included 15 percent RAP only (control material section). An overview of each day's preparation and paving activity is provided below.

- **Road Preparation (9-21-09)** —Woodworth prepared the road for paving, by grinding the existing pavement at intersections to match grades, removing raised reflectors, and pre-leveling a small portion of the roadway with conventional HMA to provide for the required finish grade.
- **Paving Day 1 (9-22-09)** —Woodworth started overlay operations at the east end of the paving demonstration by paving Test Section 4 with the RAP-only HMA mix. KCRSD performed all necessary testing for asphalt content, gradation, theoretical maximum density, volumetric properties, and in-place density tests. Testing indicated adequate compactive effort and satisfactory test results. Woodworth also provided testing services to further verify the quality of the job mix. Based on Woodworth's previous experience, they recommended increasing the virgin asphalt content by 0.2 percentage points to 4.5 percent for Paving Day 2. All parties agreed, and the mix was modified accordingly.
- **Paving Day 2 (9-23-09)** —Woodworth paved Test Section 3 with the RAP/RAS HMA mix. Initial test results indicated a high asphalt content and a fine aggregate content at or slightly above the maximum amount allowed. Also, there was a concern that the air voids in the pavement were much lower than anticipated. It was decided by representatives from KCRSD, WSDOT, Woodworth,

and LinkUp that that the RAP/RAS mix needed to be modified prior to proceeding to Test Section 2, so Test Section 1 to be paved with the RAP-only HMA mix was rescheduled for Paving Day 3 and Test Section 2 to be paved with the RAP/RAS HMA mix for Paving Day 4. The test sections were located as originally planned (see Table 1) even though the paving schedule was changed.

- **Paving Day 3 (9-24-09)** —Woodworth paved Test Section 1 with the RAP-only HMA mix. All testing verified satisfactory quality of the mix and adequate compaction. In preparation for paving with the RAP/RAS HMA mix the following day, Woodworth recommended reducing the asphalt content by 0.3 percentage points to the level of the original HMA mix design of 4.3 percent. In addition, Woodworth decided to attempt to reduce the fines in the overall mix by cleaning out the baghouse at the HMA plant.
- **Paving Day 4 (9-25-09)** —Woodworth paved Test Section 2 with the RAP/RAS HMA mix. Prior to paving, the HMA plant baghouse was cleaned out to reduce the amount of fine aggregate in the HMA mix. In addition, the asphalt content was reduced to better meet the recommended total asphalt content in the final HMA product according to the mix design plan. Testing indicated that the quality of the mix was now in compliance. The fines content of the aggregate ranged within the upper limits of the specification and compaction testing indicated the average relative density of the new overlay was slightly above the minimum requirement. A trace amount of intermittent fragments of shingles, wood, rubber, glass, and wire were detected, though the appearance of the pavement surface was typical of a well-placed and compacted HMA roadway.

4.2.4.3 Post-Construction Testing

Following final paving operations, the roadway was restriped and immediately reopened to traffic. Post-construction testing included rating the pavement condition using the WSDOT Distress Data Collection Van, recording deflections using the WSDOT falling weight deflectometer, and testing skid resistance (conducted by the King County Sherriff's office). Results of these tests are included in the presentation of findings in Section 5.3.3 Post-Construction Testing.

5. FINDINGS AND RESULTS

This section presents a brief description of the testing, findings, and results from testing conducted throughout the paving demonstration by KCRSD and WSDOT. A series of tests were conducted on the RAS and HMA products to verify compliance with project specifications and performance standards. In addition, a series of pavement tests were conducted prior to, during, and after pavement installation to evaluate initial pavement performance. Please refer to Appendix E for a matrix of the sampling and testing conducted for the paving demonstration.

Results were analyzed by KCRSD and WSDOT. A key to acronyms used in this section is provided in Appendix A. Further discussion of the significance of individual tests and detailed findings can be found in Appendix I, the KCRSD report.

5.1 RAS Testing Results

In September 2009, prior to paving, the LinkUp team collected samples of RAS from the final stockpile, three of which were tested by KCRSD to verify whether the material met the specified performance requirements. As shown in Table 2, test results revealed that the materials met the requirements regarding extraneous waste materials sampled but did not meet the gradation or moisture content requirements. For example, an average of just under two percent of the RAS did not pass the 1/2-inch sieve when the RAS specification required 100 percent to pass this largest sieve size. Also, average moisture content was about double the amount specified at about ten percent compared to the RAS specification which was set at five percent. KCRSD staff, however, determined that the materials substantially met the engineering intent for the paving demonstration and accepted them for use because they understood the materials would be further reduced in size when blended with RAP, prior to entering the mixing drum. In addition, excessive moisture content was manageable given the consistent readings. The measured moisture content was used in calibrating the final mix proportions during production.

Table 2. RAS Final Stockpile Test Results Summary (Tests conducted by KCRSD, 9/11/09)

Test procedure	Requirement	Lab Sample KC-09-1122	Lab Sample KC-09-1123	Lab Sample KC-09-1124
Gradation, 1/2-inch sieve	**100% Passing**	99%	98%	98%
Gradation, 3/8-inch sieve	**95% Minimum. Passing**	94%	92%	93%
Lighter Extraneous Material	**1.5% Maximum**	0.06%	0.01%	0.03%
Total Extraneous Material	**3.0% Maximum**	0.06%	0.01%	0.03%
Moisture Content	**5.0% Maximum**	10.0%	9.3%	10.8%

5.2 HMA Testing Results

As mentioned in Section 4.2.2.2, WSDOT conducted a series of preliminary mix design tests with samples submitted in response to the RFI by three potential RAS suppliers. Representative samples of each RAS supply were tested for extraneous materials, moisture content, aggregate gradation, and asphalt content (identified as “Pb” percent binder) in an effort to characterize the supply of RAS available from suppliers in the central Puget Sound area. All three RAS suppliers produced preliminary samples that met the draft RAS specification with one exception: the sample identified as RAS #1 exceeded the moisture content limit of 5.0 percent. Table 3 and Table 4 show the results of these tests compared to the draft material specifications for RAS used at the time of the RFI.

Table 3. Preliminary RAS Samples submitted in response to the RFI: Extraneous Materials & Moisture Content (Test conducted by WSDOT, 9/18/08)

	Lighter Extraneous Material	Total Extraneous Material	Moisture Content
RAS #1	0.5%	2.2%	8.2%
RAS #2	0.2%	0.3%	2.7%
RAS #3	0.2%	0.7%	1.4%
Specification	≤ 1.5%	≤ 3.0%	≤ 5%

Table 4. Preliminary RAS Samples submitted in response to the RFI: Gradation and Asphalt Content (Pb) (Test conducted by WSDOT, 10/14/08)

	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	Pb
RAS #1	100	100	97	89	86	67	47	39	31	22.1	19.7
RAS #2	100	100	100	97	97	74	45	38	33	25.9	16.3
RAS #3	100	100	97	90	86	66	46	40	32	24.4	22.8
Specification		100 Min.	95 Min.								

In addition to the preliminary characterization testing of the RAS samples submitted in response to the RFI, WSDOT performed informational testing on the asphalt binder contained in the RAS. Asphalt binder from each of the three RAS samples was extracted and recovered and then blended with RAP and Neat (virgin) asphalt binder and tested per AASHTO M 320 standards. The test results of the blended RAS/RAP/Neat asphalt binders were compared to Neat asphalt and Neat asphalt blended with recovered RAP binder to determine the effects attributed to the addition of recycled asphalts. This testing was important as it confirmed that adjustments to the grade of virgin asphalt binder and use of any rejuvenation additives were not required to compensate for the addition of the recycled asphalts from RAS and RAP. Table 5 shows the results of the asphalt binder testing compared to the AASHTO M 320 specifications for performance graded asphalts.

Table 5. Preliminary RAS Samples, Recovered Asphalt Binder Test Data (Test conducted by WSDOT, 12/16/08)

Asphalt Binder Properties	Rotational Viscosity	Original DSR/Grade	Original	RTFO DSR/ Grade	RTFO	PAV DSR/ Grade	PAV	
Neat Asphalt/RAP&RAS #1	0.7	1.64 / 70	74.0	3.36 / 70	73.3	4475 / -16	-16	-22
Neat Asphalt/RAP&RAS #2	0.5	1.52 / 70	74.5	2.57 / 70	71.2	3905 / -16	-19	-22
Neat Asphalt/RAP&RAS #3	0.6	3.1 / 88	88	3.6 / 70	73.9	4505 / -16	-16	-16
Neat Asphalt & 15% RAP	0.4	1.9 / 64	69	4.9 / 64	70.0	3688 / -16	-21	-22
Neat Asphalt	0.4	1.45 / 64		3.61 / 64		3997 / -22		-22
Specifications	Max 3.0	Min 1.00	Tru-Grade	Min 2.20	Tru-Grade	Max 5000	Tru-Grade	BBR Grade

WSDOT also conducted tested the RAS samples using virgin aggregate, RAP and RAS at varied percentages to determine if the combined materials could be blended together and still meet volumetric property quality standards. The preliminary test results from these RFI samples indicated that both RAS and RAP could be added to a typical 1/2-inch HMA with minimal changes needed to

adjust for the potential increase in air voids of the final product. Ultimately the decision to limit the quantity of RAS to three percent of the mix was based on efforts to stay below 30 percent recycled asphalt binder by total weight of the mix and minimize impacts to the mixture volumetric properties. Table 6 shows the volumetric data generated from the preliminary mixture testing compared to typical HMA specifications. With few exceptions, use of recycled materials increased the air voids (Va) of the 1/2-inch HMA used for this test when compared to the virgin aggregate and asphalt mixture.

Table 6. Preliminary RAS Samples submitted in response to the RFI: Volumetric Comparisons (Test conducted by WSDOT, 10/14/08)

Mix Design	Material %			Volumetric Data										
	Virgin	*RAP*	*RAS*	*Pb*	*Gmb*	*Gmm*	*Gmm @ Ndes*	*Gmm @ Nini*	*Va*	*VMA*	*VFA*	*Pbe*	*Gse*	*D/A*
Virgin	100	0	0	5.5	2.378	2.478	96.0	86.3	4.0	14.4	72	4.5	2.700	1.4
RAP	80	20	0	5.5	2.392	2.478	96.5	86.8	3.5	13.9	75	4.5	2.700	1.4
RAS #1	97	0	3	5.5	2.359	2.466	95.7	86.1	4.3	15.1	72	4.7	2.685	1.3
RAS #1	95	0	5	5.5	2.323	2.464	94.3	85.4	5.7	16.4	65	4.7	2.682	1.3
RAS #1	77	20	3	5.5	2.365	2.474	95.6	86.0	4.4	14.9	71	4.5	2.695	1.4
RAS #1	75	20	5	5.5	2.350	2.460	95.5	86.4	4.5	15.4	71	4.8	2.677	1.3
RAS #2	97	0	3	5.5	2.351	2.472	95.1	85.9	4.9	15.4	68	4.6	2.692	1.3
RAS #2	95	0	5	5.5	2.349	2.458	95.6	86.4	4.4	15.4	71	4.8	2.675	1.3
RAS #2	77	20	3	5.5	2.385	2.466	96.7	87.5	3.3	14.1	77	4.7	2.685	1.3
RAS #2	75	20	5	5.5	2.363	2.468	95.7	85.8	4.3	14.9	71	4.6	2.687	1.3
RAS #3	97	0	3	5.5	2.345	2.467	95.1	85.5	4.9	15.6	69	4.7	2.686	1.3
RAS #3	95	0	5	5.5	2.317	2.485	93.2	84.2	6.8	16.6	59	4.4	2.708	1.4
RAS #3	77	20	3	5.5	2.368	2.463	96.1	86.7	3.9	14.8	74	4.7	2.681	1.3
RAS #3	75	20	5	5.5	2.327	2.463	94.5	85.2	5.5	16.2	66	4.7	2.681	1.3
Specifications							Approx. 96.0%	≤ 89.0	Approx. 4.0%	Min. 14.0%	65 - 75			0.6 - 1.6

5.3 Paving Testing

A series of quality assurance and material performance tests were conducted prior to, during, and immediately following paving. Results were used to ensure the paving mix and installed pavement met performance standards and also to make ongoing refinements to the HMA mix and paving processes. Results for the four test sections are reported separately. Table 1 in Section 4.2.4.1 presents an overview of the four test sections.

5.3.1 Pre-Construction Testing

Pavement distress observations from the walking survey of the entire roadway were categorized and quantified for the purpose of developing Pavement Condition Indices (PCI). PCI is a numerical indicator that rates the present condition of the pavement based upon the type, quantity, and distress levels observed. A newly constructed pavement would have a PCI of 100 and a roadway that has failed would have a rating near zero. The PCI is also an indicator of the structural integrity and potential operational or safety issues associated with the pavement. PCI ratings were developed for each test section and for the entire road. The ratings are summarized in Table 7.

Table 7. Pre-Construction PCI Results (Test conducted by KCRSD, 6-29-09 through 8-4-09)

	PCI Rating	Condition Description
Test Section 1	78.0	Very Good
Test Section 2	72.0	Very Good
Test Section 3	44.0	Fair
Test Section 4	70.0	Very Good
Overall Rating	66.0	Good

The WSDOT Distress Data Collection Van conducted three types of tests during pre-construction as described below.

- Pavement Structural Condition (PSC) scores the pavement structure based on a compilation of all visible surface distresses. This score ranges from 100, a new surface void of any distress, to zero, representing total pavement failure.
- Pavement Rutting Condition (PRC) scores the extent of rutting present in the rated lane. The scale of the PRC ranges from 100, no rutting, to zero, deep rutting dependent on the length. A roadway would be considered for rehabilitation when the PRC rating is 50 or below.
- International Roughness Index (IRI). IRI is a measurement for roughness of the pavement surface. For this rating, the scoring ranges from low to high and is measured in inches per mile. The higher the score, the rougher the roadway section, with zero considered equivalent to a smooth glass surface. WSDOT uses the following rankings, shown in Table 8, when rating the IRI:

Table 8. IRI Roughness Scale

IRI (inches/mile)	Pavement Rating
Below 95	Very Good
95-170	Good
170-220	Fair
220-320	Poor
Above 320	Very Poor

Table 9 presents the results of the PSC, PRC, and IRI tests.

Table 9. Pre-construction Pavement Condition Survey Results (Test conducted by WSDOT, 7-10-09)

	PSC	PRC	IRI
Test Section 1	43.4	80.1	83
Test Section 2	24.8	76.9	94
Test Section 3	26.8	76.7	185
Test Section 4	29.8	79.4	132
Overall rating	31.2	79.0	124

Results Of Pavement Coring

On August 5, 2009, KCRSD obtained a total of 16 asphalt concrete pavement (ACP) cores from the roadway within the paving demonstration limits. Four cores were retrieved from each test section, two from each lane within the test section. A summarized description of pavement thickness and materials found in each test section is presented below:

- Test Section 1 (Cores 1 through 4): Average pavement thickness was approximately 4.5 inches. On average roughly three inches of crushed surfacing materials were found below the asphalt pavement. Silty gravel was found below the crushed surfacing layer.
- Test Section 2 (Cores 5 through 8): The pavement section was similar to those found in Test Section 1, consisting of 4.5 inches of ACP overlaying three inches of crushed surfacing. Silty gravels were encountered below the crushed surfacing layer.
- Test Section 3 (Cores 9 through 12): The pavement section consisted of about 4.5 inches of ACP overlaying approximately two inches of bituminous surface treatment (BST) consisting of densely compacted gravels bonded with a thin asphalt binder. Silty sand was encountered below the oil shot layer.
- Test Section 4 (Cores 13 through 16): The pavement section consisted of 5.5 inches of ACP overlaying about two inches of Asphalt Treated Base (ATB). Silty sands were typically found below the ATB layer.

Results of Subsurface Test Borings

On August 6, 2009, KCRSD drilled a total of six exploratory borings with at least one borehole sited in each test section to better understand subsurface soil conditions. A general description of the soils encountered in each test section is as follows.

- Test Section 1: Medium dense becoming dense silty gravel
- Test Section 2: Medium dense becoming dense silty gravel or silty sand
- Test Section 3: Loose silty sand
- Test Section 4: Loose organic silt or silty sand

No groundwater was encountered in any boreholes during drilling.

Results of Falling Weight Deflectometer Testing

In August 2009, WSDOT conducted falling weight deflectometer tests to evaluate the physical properties of the pavement section and near surface soils. Deflections are measured in mils, a linear unit of diameter equal to 0.001 of an inch. Average deflections for Test Sections 1 and 2 were typically below 20 mils. In Test Sections 3 and 4, deflections were recorded near or above 30 mils. An increase in deflection is an indicator of reduced capacity to support traffic loads over time before failure of the roadway. Because there are less deflections (i.e., pavement is stiffer) in Test Sections 1 and 2, they are in more favorable condition than Test Sections 3 and 4. This information will be taken into account when predicting the long-term performance for each of the sections.

5.3.2 Pavement Installation Testing

The volumetric data generated from production samples of HMA with RAP, sampled at the asphalt plant from outbound hauling vehicles and tested by KCRSD for Test Section 4, showed slightly lower air voids (Va) and voids in mineral aggregate (VMA) results than measured during the mix design process. While these results were lower than the original design, they were still within WSDOT acceptance tolerances (2.5 percent - 5.5 percent and 12.5 percent minimum, respectively) for field-produced HMA. The data generated from samples taken for Test Section 1 were also lower than the original design and the Va results were outside of WSDOT acceptance tolerances.[15] The decline of Va and VMA values may be attributed to the variability in the percent of binder (Pb) and aggregate gradation, most notably the increase of material passing each sieve compared to original mix design Job Mix Formula (JMF).

15 For this project, King County did not base acceptance of materials on volumetric measurements of the in-place job mix. These values are provided for informational purposes only.

Table 10 and Table 11 provide a summary of the data for these two days of production compared to the original mix design Job Mix Formula (JMF).

Table 10. Production Paving, Volumetric Data for Test Sections 4 and 1 (HMA with RAP only) (Tests conducted by KCRSD, 9/22/09 and 9/24/09)

Test Section	Material %			Volumetric Data										
	Virgin	*RAP*	*RAS*	*Pb*	*Gmb*	*Gmm*	*Gmm @ Ndes*	*Gmm @ Nini*	*Va*	*VMA*	*VFA*	*Pbe*	*Gse*	*D/A*
Section 4 (9/22/2009)	85	15	0	5.3	2.399	2.485	96.5	N/A	3.5	13.9	75	4.5	N/A	1.3
Section 4 (9/22/2009)	85	15	0	5.5	2.409	2.483	97.0	N/A	3.0	13.7	78	4.6	N/A	1.3
Section 1 (9/24/2009)	85	15	0	5.7	2.426	2.481	97.8	N/A	2.2	13.3	84	4.7	N/A	1.4
Section 1 (9/24/2009)	85	15	0	5.4	2.426	2.485	97.6	N/A	2.4	13.0	82	4.5	N/A	1.4
Average				5.5	2.415	2.484	97.2	N/A	2.8	13.5	80	4.6	N/A	1.4
JMF	100	0	0	5.3	2.374	2.475	95.9	86.4	4.1	14.4	71	4.5	2.686	1.4

Table 11. Production Paving, Aggregate Gradation and Asphalt Content Results for Test Sections 4 and 1 (HMA with RAP only) (Tests conducted by KCRSD, 9/22/09 and 9/24/09)

Test Section	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	Pb
Section 4 (9/22/2009)	100	94	82	58	39	26	18	12	9	5.9	5.3
Section 4 (9/22/2009)	100	95	83	55	36	25	18	12	9	5.9	5.5
Section 1 (9/24/2009)	100	92	83	57	38	26	18	13	9	6.5	5.7
Section 1 (9/24/2009)	100	95	84	57	37	26	18	13	9	6.4	5.4
Average	100	94	83	57	38	26	18	13	9	6.2	5.5
JMF	100	93	82	55	36	25	17	12	8	6.0	5.3

The volumetric data generated from production samples of HMA with RAP and RAS taken out of the hauling vehicle and tested by KCRSD for Test Section 3 showed significantly lower air voids (Va) results than measured during the mix design process. These results were well below the WSDOT acceptance tolerance for Va (2.5 percent - 5.5 percent) for field-produced HMA and necessitated corrective action by Woodworth. The low Va results from the material produced for Test Section 3 can be directly attributed to the increased Pb and amount of fine aggregate passing the #200 sieve as compared to the original mix design. Samples taken and tested for Test Section 2 showed an increase in Va as a result of the lower Pb but this material was also produced with a higher than designed percent of fine aggregate passing the #200 sieve. Two of the samples tested from these two days of production were outside the maximum specification limit of 7.0 percent for fine aggregate passing the #200 sieve. Table 12 and Table 13 provide a summary of the data for these two days of production compared to the original mix design Job Mix Formula (JMF).

Table 12. Production Paving, Volumetric Data for HMA with RAP and RAS for Test Sections 3 and 2 (HMA with RAP and RAS) (Tests conducted by KCRSD, 9/23/09 and 9/25/09)

Test Section	Material %			Volumetric Data										
	Virgin	*RAP*	*RAS*	*Pb*	*Gmb*	*Gmm*	*Gmm @ Ndes*	*Gmm @ Nini*	*Va*	*VMA*	*VFA*	*Pbe*	*Gse*	*D/A*
Section 3 (9/23/2009)	82	15	3	6.4	2.423	2.450	98.8	N/A	1.1	14.0	92	5.5	N/A	1.3
Section 3 (9/23/2009)	82	15	3	6.3	2.428	2.451	99.1	N/A	0.9	13.7	93	5.4	N/A	1.3
Section 2 (9/25/2009)	82	15	3	5.5	2.383	2.489	95.7	N/A	4.3	14.6	71	4.5	N/A	1.6
Section 2 (9/25/2009)	82	15	3	5.7	2.404	2.464	97.6	N/A	2.4	14.0	83	5.0	N/A	1.4
Section 2 (9/25/2009)	82	15	3	5.8	2.405	2.472	97.3	N/A	2.7	14.1	81	4.9	N/A	1.4
Average				5.9	2.409	2.465	97.4	N/A	2.3	14.1	84	5.1	N/A	1.4
JMF	82	15	3	5.6	2.369	2.466	96.1	86.7	3.9	14.2	72	4.4	2.632	1.4

Table 13. Production Paving, Aggregate Gradation and Asphalt Content Results for HMA with RAP and RAS for Test Sections 3 and 2 (HMA with RAP and RAS) (Tests conducted by KCRSD, 9/23/09 and 9/25/09)

Test Section	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	Pb
Section 3 (9/23/2009	100	91	82	58	39	27	19	14	10	7.2	6.4
Section 3 (9/23/2009	100	91	81	56	38	27	19	13	9	6.8	6.3
Section 2 (9/25/2009)	100	95	87	61	42	29	21	15	11	7.0	5.5
Section 2 (9/25/2009)	100	95	84	57	39	27	19	14	10	7.2	5.7
Section 2 (9/25/2009)	100	92	83	57	38	26	19	13	10	6.8	5.8
Average	100	93	83	58	39	27	19	14	10	7.0	5.9
JMF	100	94	84	57	39	27	19	13	8	6.3	5.6

5.3.3 Post-Construction Testing

In December 2009, WSDOT conducted a post-construction pavement condition survey using laser equipment mounted to the WSDOT Distress Data Collection Van. The survey serves as a baseline for documenting deterioration of each roadway test section over time. Test results from the WSDOT post-construction pavement condition survey are summarized below in Table 14.

Table 14. Post-Construction Pavement Condition Survey (Test conducted by WSDOT, 12/2/09)

	Pavement Structural Condition (PSC)	Pavement Rutting Condition (PRC)	IRI (roughness)
Test Section 1	100	95.6	68
Test Section 2	99.8	97.6	60
Test Section 3	100	95.0	88
Test Section 4	99.7	96.1	78
Overall Rating	99.9	96.1	74

The survey revealed that the newly paved roadway surface is in near perfect visual condition with minutely recorded rutting. The roughness (IRI) of the roadway measured below 95 in all test sections indicating a relatively smooth surface. However, Test Sections 3 and 4 rated about 20 points higher than Test Sections 1 and 2. This may be due to traveling over the existing Newaukum Creek Bridge located in Test Section 3 and/or accelerating or decelerating during testing.

WSDOT conducted post-construction falling weight deflectometer (FWD) testing along the roadway in October 2009. Data obtained from testing is in the process of analysis. Information was not complete prior to the release of this report and will be included in a supplemental report from KCRSD in March 2010.

Roadway skid resistance testing was conducted by the King County Sherriff's office. Testing was performed within each test section in October 2009 for dry pavement and in January 2010 for wet pavement surface conditions. The results of skid resistance testing are drag factors which are used throughout the accident reconstruction industry as an indicator of skid resistance. A summary of the skid test results for both dry and wet surface conditions are summarized below in Table 15.

Table 15. Drag Factor Test Results in Both Dry and Wet Road Conditions (Tests conducted by Major Accident Response and Reconstruction Unit (MARR) of the King County Sherriff's office, 10-12-09 for dry roadway and 1-04-10 for wet roadway)

	Dry Roadway		Wet Roadway	
	Conventional Braking	***Anti-Lock Braking***	***Conventional Braking***	***Anti-Lock Braking***
Test Section 1	0.71	0.83	0.66	0.79
Test Section 2	0.70	0.86	0.68	0.82
Test Section 3	0.67	0.81	0.66	0.80
Test Section 4	0.72	0.87	0.73	0.83
Overall Rating	0.70	0.84	0.68	0.81

Test results indicated that the overall skid resistance for both dry and wet conditions recorded on the paving demonstration roadway was comparable to those found on other similar King County roadways.

6. CONCLUSIONS

The paving demonstration fully met two of the three study objectives, and partially met the third objective. To fully meet the third objective, long-term monitoring will be required to gain wide acceptance of the performance test results. **Results from the extensive initial materials engineering tests conducted by the team indicate that using RAS as a part of the HMA mix has had no negative effect on pavement performance.**

Study Objectives

- Align the demonstration with the interests and standards of participating agencies and stakeholders.
- Design the study to evaluate the performance of RAS-modified HMA with a high degree of certainty; a key strategy was to isolate RAS as a variable.
- Capture objective engineering data in an effort to gain wide acceptance of the performance test results.

The finished roadway surface is in near perfect visual condition with minutely recorded rutting and skid resistance testing showing no noticeable difference in resistance. Testing verified that all but one Test Section substantially met project specifications and materials standards. Further testing, analysis, and documentation on the long-term performance of this roadway will continue for a minimum of three years to verify the impact on using RAS on public roadways in King County.

The paving demonstration results indicate that the RAS contributed a greater amount of asphalt binder to the final HMA product than anticipated. Both Woodworth and WSDOT suspect that double grinding the RAS, which was needed to meet the RAS gradation specification, enabled more of the RAS-embedded asphalt to be released and effectively utilized in the HMA than originally predicted. Further research and analysis is necessary to confirm this hypothesis.

Paving in process at SE 416th St near Enumclaw, Washington

The core team learned much about RAS sampling and testing while verifying that the RAS product met the RAS specification. The core team employed more stringent visual inspection of an existing stockpile of tear-off asphalt shingles than originally specified to address ACM findings and reduce the likelihood of ACM or extraneous materials ending up in the finished product. At the same time, differing results of testing RAS using PLM and TEM and limited regulatory guidance for testing ACM in RAS point to a clear need to develop standard sampling and testing methods for detecting ACM in RAS and other tear-off roofing materials.

Just as significant, the paving demonstration illustrated the critical importance of a multi-party, partnership approach to such research and development efforts. The various challenges faced by the team

were overcome in large part due to the collaborative approach to problem solving that team members used. Without the productive input and engagement of KCRSD, WSDOT, and Woodworth, the paving demonstration may not have been successfully implemented.

7. NEXT STEPS

In 2010 and beyond, the LinkUp team will build on the paving demonstration to advance the development of infrastructure and end markets for recycling tear-off shingles. This work will involve strategically engaging existing and new stakeholders to share findings and results as well as conducting focused research to further explore questions and issues that surfaced during the paving demonstration. In addition, LinkUp will continue its partnership with KCRSD and WSDOT to monitor and test pavement performance of the paving demonstration. These activities are highlighted below.

7.1 Sharing Results and Stakeholder Engagement

A key goal for 2010 and beyond is to reach out to existing and new stakeholders to share results and explore opportunities to expand infrastructure and end markets for recycling tear-off asphalt shingles. Presented below are some of the important outreach initiatives identified by the LinkUp team and advisory group:

- **Regional Stakeholders.** LinkUp will convene a regional stakeholder meeting in the first quarter of 2010 to present results of the paving demonstration. The goal of this meeting is to re-engage the original stakeholder group as well as engage new stakeholders to share findings from the paving demonstration, ongoing pavement performance monitoring, and future efforts to develop tear-off asphalt shingles recycling markets for paving applications.
- **KCRSD.** LinkUp will continue to build on its successful partnership with KCRSD. Early in 2010, members of the core team will present results to the KCRSD management team. LinkUp will continue to talk to KCRSD about additional demonstration projects.
- **WSDOT.** LinkUp will continue working with WSDOT to better understand the process for securing a provisional or permissive specification for using RAS in HMA, to share national developments, and to identify demonstration opportunities for a state road.
- **SPU and SDOT.** Both SPU and SDOT have expressed interest in partnering with LinkUp to advance RAS in HMA. SPU expressed interest in helping develop a clean stream of tear-off shingles for recycling. SDOT is interested in exploring a paving demonstration on a Seattle road in partnership with another jurisdiction, such as King County, to create a project large enough meet the minimum tonnage for an HMA producer to justify production of an experimental mix.
- **HMA Producers and Paving Contractors.** LinkUp will strategically reach out to HMA producers and paving contractors to share results and lessons of the paving demonstration as well as to learn

more about their current interest in and use of RAS in paving applications. Woodworth has offered to propose a LinkUp presentation at the Washington Asphalt Pavement Association's May 2010 meeting. HMA producers and paving contractors will be important partners for driving toward a state permissive HMA specification for using RAS.

- **RAS Suppliers.** The paving demonstration pointed to the importance of visual inspections and sorting of incoming tear-off asphalt shingles. Reaching out to RAS suppliers, such as roofers and recyclers, to better understand material sorting procedures and opportunities will benefit future RAS demonstrations and RAS specification development.
- **Regional and National Partners.** LinkUp intends to connect with EPA, the Federal Highway Administration, and other asphalt shingle recycling efforts across the country to coordinate current and future market development efforts to test and use RAS in HMA. Initial activities could include sharing lessons learned, establishing standards and protocols, and jointly pursuing research and development. LinkUp is interested in coordinating with CMRA and two specific initiatives: the Owens Corning Heritage Environmental Services partnership and the Roofs to Roads program in Boulder, Colo. Given the growing interest on the west coast, the team will also reach out the British Columbia, Oregon, and California as well.

7.2 Research

Based on the paving demonstration, the LinkUp team and the advisory group have identified several research opportunities to pursue in 2010 and beyond to further advance RAS market development. Some of these ideas are highlighted below:

- Conduct interviews with HMA producers to better understand how RAS is currently used on private roads in Washington and Oregon. Since the start of the Shingles in Paving Project, considerable advances have been made regionally and nationally in both the processing and use of RAS in HMA. Understanding the current use of RAS for private roads will contribute to the growing body of research on using RAS in HMA for public roads.
- Further investigate how much asphalt binder RAS is contributing to the total asphalt in the final HMA. During the paving demonstration, testing results indicated that RAS contributed a greater amount of asphalt than expected. Research projects elsewhere in the nation are also pursuing this question. LinkUp will investigate this question using results from the paving demonstration and work with partners elsewhere to contribute to this body of work on a national scale.
- Develop a model to help evaluate costs and savings associated with using RAS in HMA. This model would be based on data from the current paving demonstration as well as data from other sources and would address different scenarios, such as changes in sampling and testing protocols, virgin asphalt prices, and RAS processing.
- Work with national partners to develop standards for sampling and testing to accurately and cost-effectively determine the presence of ACM in tear-off asphalt shingle roofing debris and RAS. As indicated by the modifications made to the asbestos sampling and testing protocols during

the paving demonstration as described in 4.2.2.1 RAS Specification, there is a need to develop better guidance for identifying the presence of ACM in these materials. An investigation into this topic is underway on the national level.[16] Similarly, a shingle manufacturer has partnered with an environmental services company to roll out a national program with local recycling opportunities and standardized asbestos testing.[17]

7.3 Future Testing

KCRSD will complete initial testing of the paving demonstration roadway in early 2010, including falling weight deflectometer testing, current pavement thicknesses, subsurface conditions, and traffic analysis to predict the long-term performance of each test section. In addition, dependent on weather conditions, a walking pavement condition survey will be conducted to provide an additional baseline for determining long-term performance.

KCRSD will continue to monitor the demonstration roadway for at least three years. After that time, the long-term structural effects of using RAS can be assessed. This continued monitoring will include the following procedures:

- Conduct a yearly pavement condition survey by walking the site and documenting all distressed areas.
- Conduct a yearly pavement condition survey using the WSDOT Distress Data Collection Van.
- After three years of service, conduct skid testing in the dry and wet conditions.

At the end of the three-year period, KCRSD will analyze the results and submit a supplemental report summarizing the findings and provide recommendations for a provisional or permissive HMA specification for using RAS in the KCRSD Overlay Program or other King County projects.

16 See, for example, the following two documents:

EPA advisory notice: *Advisory Regarding Availability of an Improved Asbestos Bulk Sample Analysis Test Method; Supplementary Information on Bulk Sample Collection and Analysis*, dated: July 21, 1994. Issued by Lynn R. Goldman, Assistant EPA Administrator, Office of Prevention, Pesticides and Toxic Substances, Federal Register (FR) Doc. 94-18665; Filed 7-29-94)

Advances in Environmental Measurement Methods of Asbestos; Edited by Beard and Roover. http://books.google.com/books?id=e8SDWXp9VusC&pg=PA113&lpg=PA113&dq=PLM+vs.+TEM+methods+for+asbestos+analysis&source=bl&ots=TfF4fs5_lk&sig=2A0bv1bOg_bivr3GMOGiSEBi3Js&hl=en&ei=3ayOSsWZMY6eMcPe9a8K&sa=X&oi=book_result&ct=result&resnum=3#v=onepage&q=&f=false Including the chapter article by Frasca, et. al. 2000).

17 Owens Corning News Release, November 3, 2009. http://www.prnewswire.com/news-releases/owens-corning-launches-shingle-recycling-program-68839327.html